STRENGTH INVESTIGATION ON RESISTANCE SPOT WELDING OF LOW CARBON STEEL AND STAINLESS STEEL

MOHD NUR SYAFFIQ BIN MAHMOOD

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ABSTRACT

Resistance spot welding (RSW) had been widely used in automotive industry; because of their advantages easily to process and low cost, high speed and high production, suitability for automation. About 2000-7000 spot welds were used in joining modern vehicles. This project deals with the investigation of failure mode and mechanical properties of weld joint of low galvanized steel and stainless Steel. The main objective of this project is strength investigation using RSW of low carbon steel and stainless steel. For design of experiment, Taguchi method was employed by using Minitab software, and total nine sets experiment with 3 type of parameter (current, squeeze time, pressure) were conducted. The studies of mechanical properties, are consists of various tests; Tensile test, Coach Peel test, Hardness test, microstructure to analyze and investigate the weldability of galvanized Steel and stainless Steel sheet. Visual inspection was done to determine the failure mode of the spot welding. As a result, tensile test have larger strength variation than the coach-peel test. Wider width and depth of weld nugget affect the weldability of the welding. Different parameters were obtained for optimum parameter for tensile test and coach peel test by using Taguchi method. Almost pullout failure mode occurs where failure at heat affected zone (HAZ) around the nugget circumference.

ABSTRAK

Kimpalan rintangan spot telah digunakan secara meluas dalam industri automotif kerana kelebihan mereka mudah untuk di proses dan kos yang rendah, kelajuan yang tinggi dan pengeluaran yang banyak, kesesuaian untuk automasi. Lebih kurang 2000-7000 kimpalan spot telah digunakan untuk pencantuman kenderaan moden. Projek ini meliputi penyiasatan mod kegagalan dan sifat-sifat mekanik sambungan kimpalan keluli tergalvani rendah dan keluli tahan karat. Objektif utama projek ini adalah siasatan kekuatan menggunakan kimpalan rintangan spot kepada keluli karbon rendah dan keluli tahan karat. Bagi procedure eksperimen, kaedah Taguchi telah bekerja dengan menggunakan perisian Minitab, dan jumlah eksperimen sebanyak sembilan set dengan 3 jenis parameter (arus, masa tekanan, tekanan) telah dijalankan. Kajian sifat-sifat mekanik, yang terdiri daripada pelbagai ujian iaitu ujian tegangan, ujian pengupasan coach, ujian kekerasan, mikrostruktur untuk menganalisis dan menyiasat kebolehan kimpalan kepingan keluli tergalvani dan keluli tahan karat. Pemeriksaan visual telah dijalankan untuk menentukan mod kegagalan kimpalan. Hasilnya, ujian tegangan mempunyai kekuatan lebih besar daripada ujian pengupasan ‘Coach’. Keluasan lebar dan ke dalam spot kimpalan menjejaskan kebolehan kimpalan. Parameter yang berbeza diperolehi untuk mendapatkan parameter optimum untuk ujian tegangan dan ujian pengupasan coach dengan menggunakan kaedah Taguchi. Kebanyakan mod kegagalan berlaku ialah penarikan di mana kegagalan di zon terjejas haba di lilitan spot kimpalan.

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RSW	Resistance Spot Welding
GS	Galvanized Steel
SS	Stainless Steel
RSEW	Resistance Seam Welding
PW	Resistance Projection Welding
DOE	Design of Experiment
OA	Orthogonal Array
AC	Alternating Current
DC	Direct Current
LED	Light Emitting Diode
S/N	Signal-to-Noise
ANOVA	Analysis of Variance
FZS	Fusion Zone Size
HAZ	Heat Affected Zone
BM	Base Metal

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Nowadays, economic and environmental considerations are resulted in research in the automotive industry to form better designs and material combinations for reducing vehicle mass, low fuel consumption and the most important is structural integrity which increases the crashworthiness of vehicles. Typically, there are about an average of 2000–7000 spot welds in a modern vehicle. In seeking production optimization, resistance spot welding (RSW) is a key technology because a technique most widely used for bonding during automotive assembly. Simplicity, fast (low process time), low cost and automation possibility are among the advantages of this process. In addition, resistance spot welding does not alter the weight of materials very much as compared to traditional arc welding (Chao, 2003; Bayraktar *et al.*, 2004; D. J. Radakovic *et al.*, 2008; Khan *et al.*, 2008; Goodarzi *et al.*, 2009; Pereira *et al.*, 2010; Mehdi, 2010; Badheka *et al.*, 2010; Charde and Arumugam, 2011; Pouranvari, 2011; Jung, 2011; Hayat, 2011,2012; Xu, Chen *et al.*, 2012; Hamidinejad *et al.*, 2012).

The project title is “Strength Investigation on Resistance Spot Welding of Low Carbon Steel and Stainless Steel”. From literature low carbon steel and stainless steel possess a good combination of mechanical properties, weldability, formability and resist to corrosion (Kola *et al.*, 2012). Type of low carbon steel in this research is Galvanized

Steel. The project research is to obtain the optimize parameter in RSW with good weldability of the dissimilar welding.

1.2 PROBLEM STATEMENT

Common problems occur in dissimilar metal joining is the parameters setup to obtain a high strength welded joint (Oba, 2006; Hamidinejad *et al.*, 2012). This happens because of different thermal conductivity and the different ways in which metals respond to heat (Hasanbaşoğlu and Kaçar, 2007; Tewari, 2010; Miller, 2012; Xu *et al.*, 2012). In order to overcome the problem is by controlling RSW parameters, and by using the DOE for predicting optimize parameter. Despite that RSW of galvanized steel is difficult because of the zinc coating. The melting point of the zinc coating is lower than the fusion temperature of the steel sheet This causes the zinc to vaporize and tendency alloying with the electrode resulting in increased tool wear, and effecting the weldability (Thakur *et al.*, 2010; Miller, 2012).

1.3 OBJECTIVE

This research is focus on:

i. To control and identify the optimum parameters affecting the weldability.
ii. To investigate and characterize the failure mode of dissimilar resistance spot welds between galvanized steel and stainless steel.

1.4 SCOPE OF RESEARCH

In order to achieve the objective, it should have proper arrangement of scopes project.This research is focusing on the strength of resistance spot weld joints of different parameters (Current, Squeeze Time and Pressure). The welded samples were all equal size and underwent tensile test, coach peel test and metallurgical testing to characterize the formation of weld nuggets.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

A literature search was performed to study and analysis the resistance spot welding and self-pierce riveting process. It also includes the investigation of what others have done in this area.

2.2 DISSIMILAR WELDING

Dissimilar metal welding are common in found in construction where welding is involve because of their excellent performance to the function of the whole structure. Dissimilar metal welding involves two or more different metals or alloys joining together (M. Alenius *et al.*, 2006). In joining two dissimilar metals, several problems arise, related to the different on physical and mechanical properties, microstructure, chemical composition, melting point, electrical resistivity, thermal conductivity and thermal coefficient (Saeed *et al.*, 2010; Kola *et al.*, 2012). Differences in the electrical resistivity and thermal conductivity of two dissimilar steel in RSW will lead to an asymmetrical weld nugget in joints (Mehdi, 2010). Figure 2.1 shows the asymmetrical weld of galvanizes steel and stainless steel.

Another common problem in dissimilar welding is an intermetallic compound (IMC) layer is form (Xu *et al.*, 2012; Liu *et al.*, 2013). It is believed that brittle intermetallic layers are the main reason for poor dissimilar joint performance because fatigue failure of dissimilar welds always occurred at the interface where intermetallic compounds were formed. Which typically have a low critical stress intensity factor and easily to crack (X. Sun *et al.*, 2004; Tewari, 2010; Liu *et al.*, 2010, 2013).

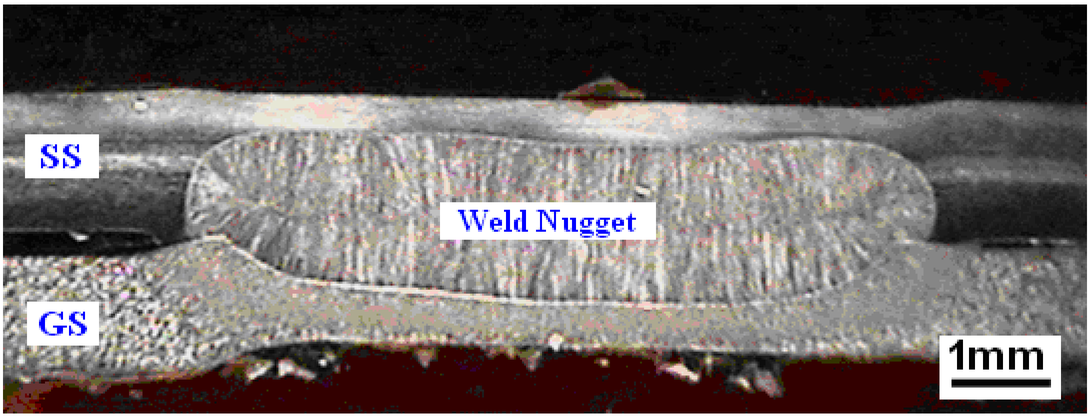


Figure 2.1: Macrostructure of dissimilar RSW between stainless steel and galvanized steel

Source: Marashi *et al.*, 2008

2.3 RESISTANCE WELDING

There are several types of resistance welding which are Resistance spot welding (RSW), resistance seam welding (RSEW) and resistance projection welding (PW). This process has been predominant mode in joining process in the manufacturing industries and automotive production (Chao, 2003; Oba, 2006; Kahraman, 2007; D. J. Radakovic And M. Tumuluru, 2008; Thakur *et al.*, 2010; Tewari, 2010; Pouranvari, 2011).

As the name is resistance welding, it is refer to the material resistance to the flow of electric current that causes a localized heating in the joint and weld is made (Tewari, 2010; Miller, 2012). The process is completed within a specified cycle time. Generally, melting occurs at the faying surface during welding. The Resistance Spot

Welding (RSW) is getting significant importance in manufacturing car, bus and railway bodies etc. due to automatic and fast process (Thakur *et al.*, 2010).

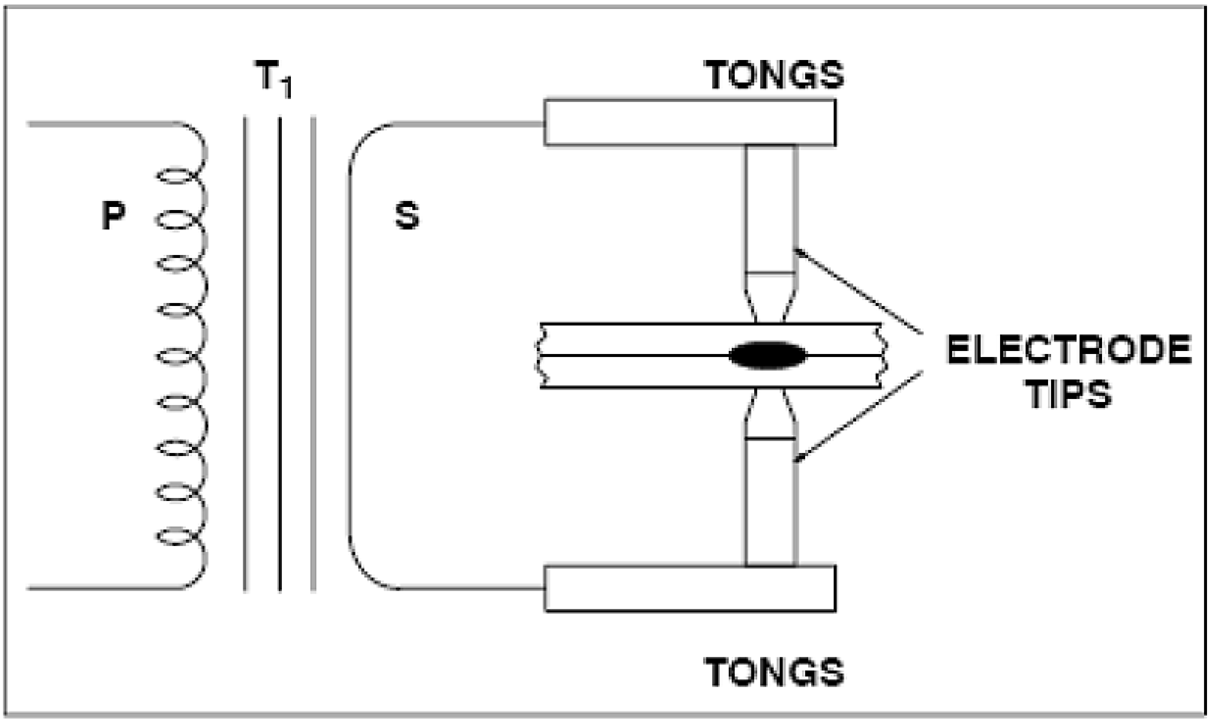


Figure 2.2: Resistance Spot Welding Machine with workpiece

Source: Jenis, 2009

2.4 PRINCIPLES OF RESISTANCE SPOT WELDING

Resistance spot welding(RSW) is one of the oldest of the electric welding processes today and the technique applied for joining almost all known metals (Tewari, 2010; Hayat, 2011). It is a process of joining metal components through the fusion of discrete spots at the interface of the work pieces (Pereira *et al.*, 2010). RSW process involves electric current and mechanical force of the electrode tips of a proper magnitude for a length of time (Pouranvari, 2011).The flow of electric current via two copper electrodes tips that also press the work sheets together to form weld (Charde and Arumugam, 2011). The weld nugget is formed due to the fusion of the melted metal localized heating in the joint due to the resistance of the joint surfaces of the base metal to electrical current flow (Goodarzi *et al.*, 2009).

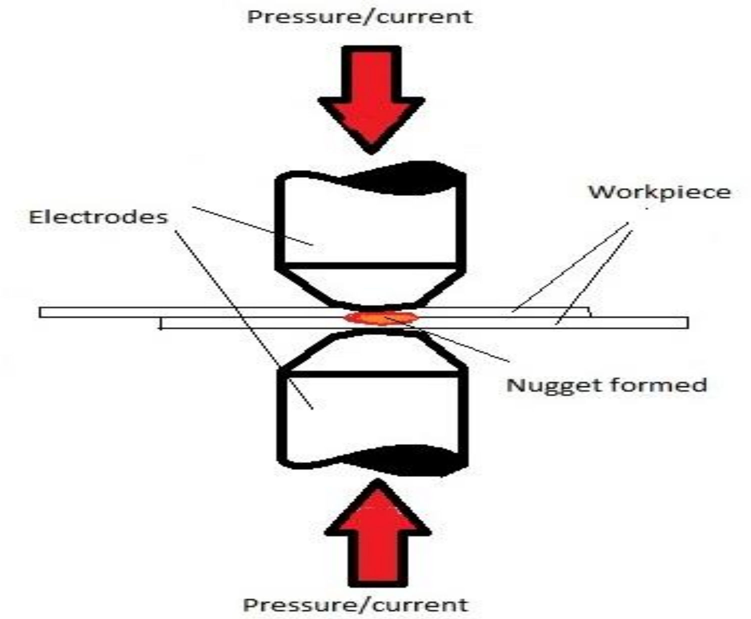


Figure 2.3: Schematic of the Resistance Spot Welding process

Source: Jenis, 2009

2.5 SPOT WELDS PARAMETERS

A quality desired product in resistance spot welding is need to either by control the changing variables that affect during welding process or the parameters that affect the process (Oba, 2006).

2.5.1 The Parameters in Resistance Spot Welding

The three main parameters in spot welding well known are electrode force, welding current and welding time. These are the most important welding parameters in resistance spot weld (Qiu, 2009). In order to produce good quality weld the above parameters must be controlled properly. The amount of heat generated in this process is governed by the formula,

$$Q = I2\ R\ T \qquad (2.1)$$

Where

Q = heat generated, Joules

I = current, Amperes

R = resistance of the work piece, Ohms

T = time of current flow, second

Source: Thakur *et al.*, 2010

Figure 2.4 below shows the procedure of the welding parameter on resistance spot weld.

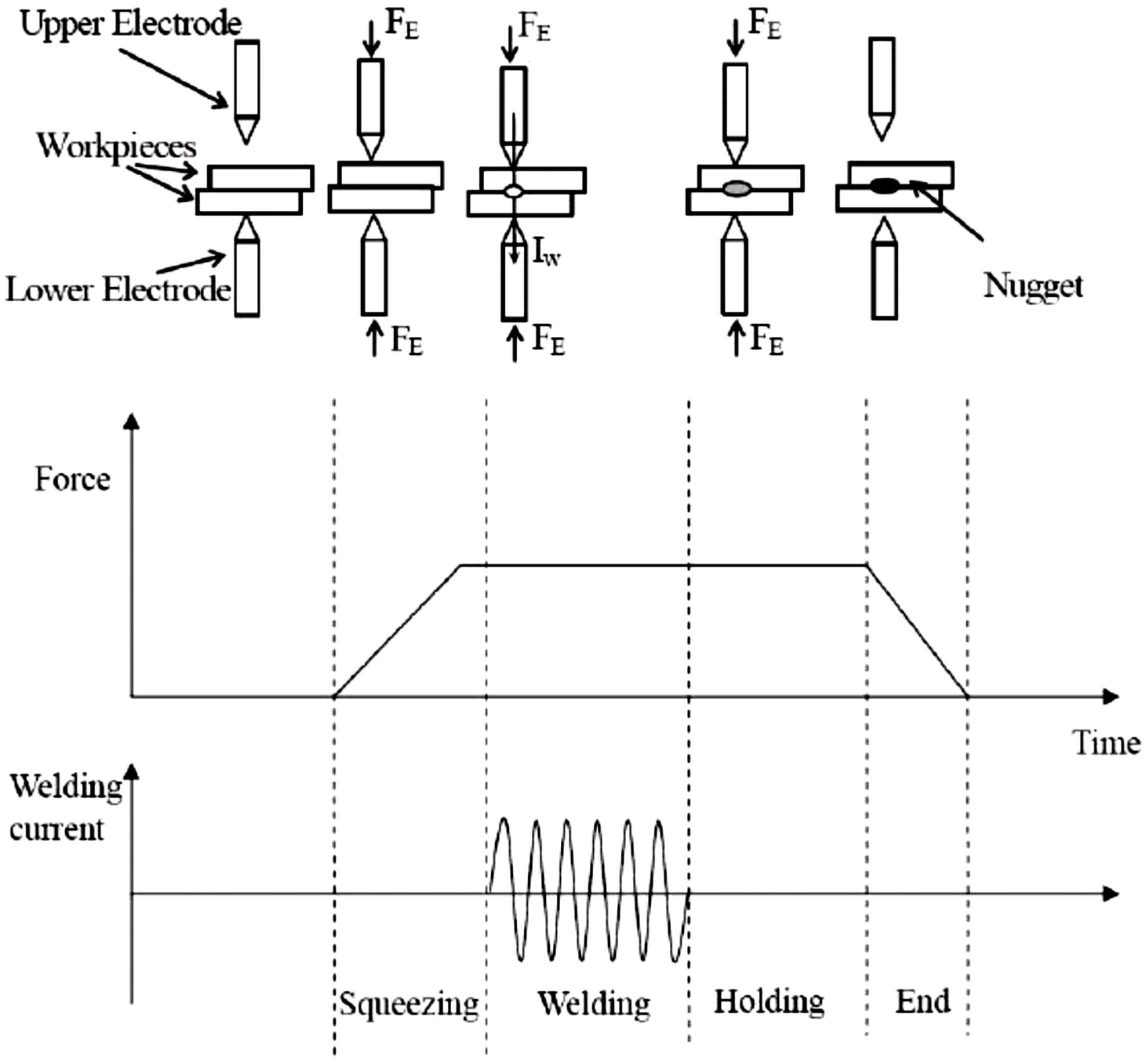


Figure 2.4: Procedure of RSW

Source: Salem, 2011

2.5.1.1 Welding Current

Welding current is one of most the important parameter in the welding process. In resistance spot welding, current is important for determining the heat generation from the process. An optimum amount of welding current is generally required to produce adequate heat energy for a weld nugget to form with minimum size diameter. However, excess welding current causes void and crack formations (Qiu, 2009; Salem, 2011).

On the basis of macrostructure analysis, it can be stated that the higher the welding current that is used, the larger the fusion zone (Mehdi, 2010; A. Aravinthan And C. Nachimani, 2011; Pouranvari, 2011; Kola *et al.*, 2012). Lower electrical resistance of carbon steels, which is even lower for low carbon galvanized steel, but its higher thermal conductivity compared to stainless steel which leads to smaller fusion zone in the former. Heat affected zone (HAZ) in the galvanized steel side is wider than that in the stainless steel side. This determine that galvanized related to higher thermal conductivity as shows in Figure 2.5 (Pouranvari *et al.*, 2008). Figure 2.6 Shows that the fusion zone size (FZS) of both stainless steel and galvanized steel side increases with the welding current with the exception of really high currents of more than 11 kA which show a decrease in the FZS due to expulsion. Optimum welding current that produce good weld quality has to be determined and selected in the resistance welding process (Oba, 2006).

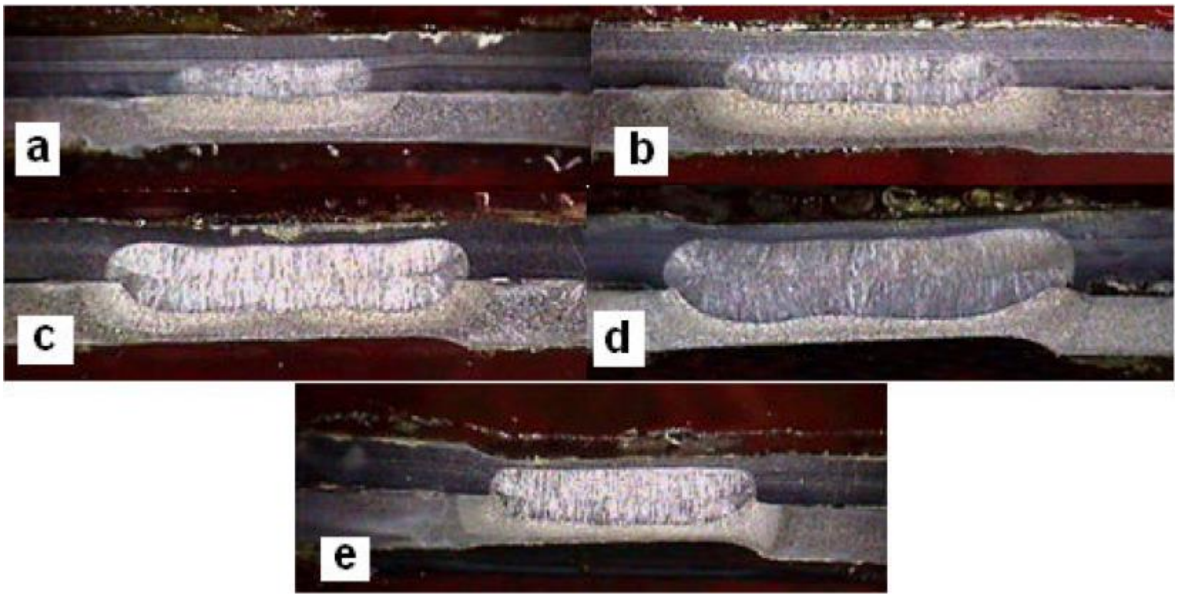


Figure 2.5: Effect of welding current on the weld nugget growth: a) 8kA b) 9kA c) 10 kA d) 11 kA e) <11 kA

Source: M. Pouranvari *et al.*,2008

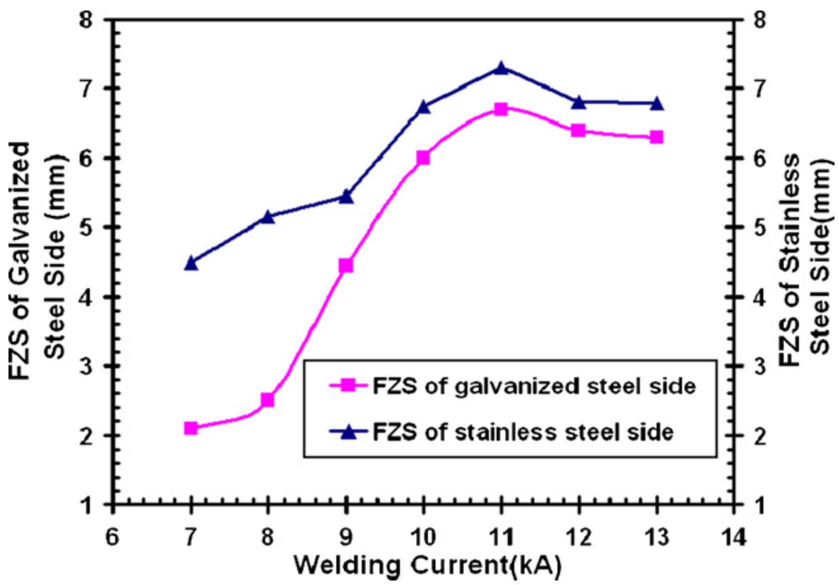


Figure 2.6: Effect of welding current on the FZS of GS and SS side

Source: Marashi *et al.*, 2008

2.5.1.2 Weld Time

Weld time is the time during which electric current is applied to the metal sheets for welding. In the welding process, when the welding time increase the size of weld nugget also increase. This is because the relation of the heat generation is directly proportional to the welding time. From the process, the heat transfer from the electric current to the workpiece, usually start from the weld zone then to the surrounding base metals of workpiece. In AC systems, the weld time is expressed in cycles (one cycle is 1/60 of a second in a 60 Hz power system), while millisecond is used for DC systems. During squeeze time, metal sheets are placed in position and clamped by electrodes (Jung, 2011).

Weld time increased, the weld strength initially shows an increase due to sufficient time given for the weld to develop. However at prolonged weld time, would increase the softening effect, overheating causes the molten metal to expel from the weld zone and hence the joint strength decrease (Salem, 2011; Charde and Arumugam, 2011).

2.5.1.3 Squeeze Time

Squeeze time as shown in Figure 2.4, is a time where pressure application and weld to occur in between. During squeeze time, metal sheets are placed in position and clamped by electrodes. When the electrode force has reached the desired level, welding proceeds by the application of current. During this time, melting and joining occurs (Jung, 2011). For the process, the squeeze time required level of the pressure is set for the electrode pressing pressure to the workpiece before the electric current is flow and weld is form (Oba, 2006).

2.5.1.4 Hold Time

Hold time is the period of time, after the welding time is complete and occurred when the electrodes are still applied to the sheet with current switched off but pressure continued. This time is to chill the welded part. The period of hold time must be set optimum to give time for the molten metal to solidify but it must not be too long to prevent the heat in the weld spot to spread to the electrode and heating it. The electrode will then get more exposed to wear. In addition, the thicker the workpiece the longer the hold time needed (Oba, 2006; Kahraman, 2007).

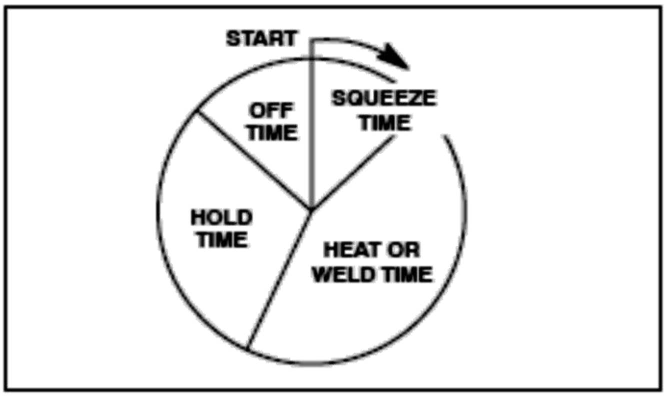


Figure 2.7: Welding Time Cycle

2.6 MATERIAL SELECTION

Stainless steel and low carbon steel such as Galvanized steel formed a good combination of formability, weldability, mechanical properties and resistance to corrosion. This combination of steels is mostly used in the power generation industry (Kola *et al.*, 2012).

2.6.1 Galvanized Steel

Galvanized steel is chemically treated steel which prevent it from corroding. It is because the steel was coated in layers of protective metal that is zinc oxide because which does not get rust easily. The coating gives the steel a harder, durable and to hard scratch finish. Galvanizes steel commonly used as infrastructure to ensure that the structure will withstand corrosion for longer period. Galvanized steel frames are used in essential industries such as power infrastructure where failure cannot be tolerated. Steel frames used in commercial buildings and residential homes also use galvanized steel to form structures that will last. Bridges are made with galvanized steel to withstand water vapor from rivers or the sea. Structures made with galvanized steel typically need less maintenance than those formed from other materials, which are prone to rusting. Galvanizes steel is lower electrical resistance than low carbon steel but high conductivity (Marashi *et al.,* 2008; M. Pouranvari *et al.,* 2008; Mehdi, 2010).

The common ways of making steel resist rust is by alloying (combining) it with a metal that is not likely to corrode for example zinc. The steel was bonded to zinc permanently by chemical reaction when submerged the steel in melted zinc. The outer layer is all zinc, but successive layers are a mixture of iron and zinc, with an internal layer of pure steel. The more demanding of galvanized steel sheet in weldability than of ordinary steel sheets because of the existence of spatter generating and cause electrode pollution during the spot welding. The application of galvanized steel sheets is limited in extensive automatic fabrication of automotive products (Hamidinejad *et al.*, 2012).

2.6.2 Stainless Steel

Stainless steel is made from several numbers of different steels and was used for their anti-corrosive element to resist of corrosive environments. It ensures for longer lasting and safety in in the used for example tools and infrastructure. Stainless steel is an earth friendly material because it can be recycled by melted it down and made into something else.

Stainless steel is usually made by chromium minimum 10.5% to make the steel stainless. A layer of chromium oxide film on the steel improves the corrosion resistance. Despite that, there are other elements used to make stainless steel. It's including nitrogen, molybdenum and nickel. The mixing of these elements together enables a variety of properties in machining, forming and welding and also welding because of different crystal structures form.

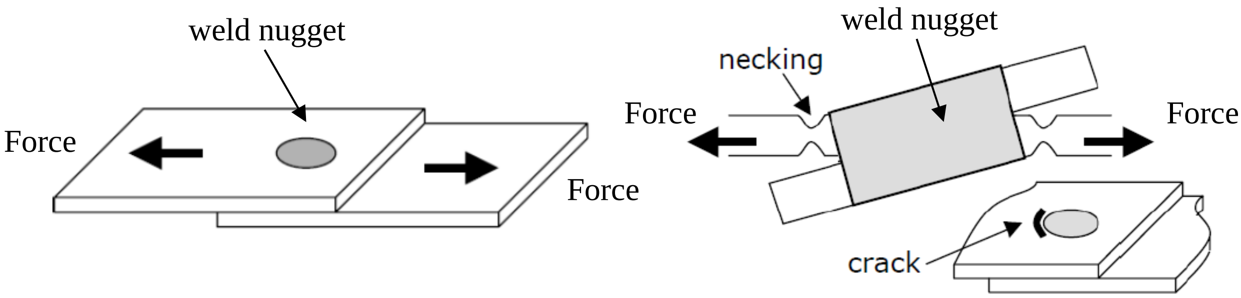
2.7 MECHANICAL TEST

Mechanical testing is an important aspect of weldability study. Such testing is either for revealing important welds characteristics, such as weld nugget diameter or weld button size, or for obtaining and evaluating the quantitative measures of weld's strength. Mechanical testing of a weldment can be static or dynamic test and among the static test, tension shear or tensile shear testing is commonly used in determining weld strength or the tensile strength of the welded joints because it is easy to conduct the test and the specimens for the test is simple in fabrication.

2.7.1 Failure Mode

Failure mode is a qualitative measure of resistance spot weld (RSW) weldability performance. The failure developed criterions of spot welds are performing the strength test using interfacial and pullout mode.

Generally, failure mode in resistance spot weld (RSW) is the manner in which spot weld fails which occurs in two modes interfacial and pullout mode (Chao, 2003). In the interfacial mode, failure occurs via crack propagation through the fusion zone as shown Figure 2.8. In the pullout mode, failure occurs via complete or partial nugget withdrawal from one sheet as shown in Figure 2.9. Failure mode of RSW can significantly affect their energy absorption capability and load carrying capacity. Spot welds that fail in nugget pullout mode provide higher peak loads and energy absorption levels than those spot welds which fail in interfacial failure mode. To ensure reliability of the spot welds during automotive lifetime, optimized parameters should be determine so that failure mode will be guaranteed (Chao, 2003; Goodarzi *et al.*, 2009; M. Pouranvari and P. Marashi, 2009).



(a) (b)

Figure 2.8: Load direction and failure mechanism of interfacial mode; (a) pulling force direction, (b) material failure

Source: Badheka *et al.*, 2010